WASTE HEAT RECOVERY VIA ORGANIC RANKINE CYCLE: RESULTS OF A ERA-SME TECHNOLOGY TRANSFER PROJECT

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EXTENDED ABSTRACT

INTRODUCTION

The main goal of the EraSME project "Waste heat recovery via an Organic Rankine Cycle", completed by partners Howest (Belgium), Ghent University (Belgium) and University of Applied Sciences Stuttgart (Germany) between 1 January 2010 and 31 December 2012, was to find an entrance in Flanders for the Organic Rankine Cycle (ORC) technology in applications with sufficient amounts of waste heat at high enough temperatures. The project was preceded by a similar study that focused on renewable energy sources.

Several tools were developed to aid in the viability assessment, the selection, and the sizing of ORC installations. With these methods, a fast determination of feasibility is possible. The outcome is based on the size, nature and temperature of the waste heat stream as well as the electricity price. An estimate can be given of the net power output, the investment costs and the economic feasibility. The tool is linked to a database of ORC manufacturer specifications.

Another objective of the project was to keep track of the evolution in ORC market supply, both commercial and precommercial. We also looked beyond the product line of the main manufacturers. Some ORCs are developed for specific applications.

ORC technology was benchmarked against alternatives for waste heat recovery, such as: steam turbines, heat pumps and absorption cooling. ORC in or as a combined heat and power (CHP) system was also examined.

A laboratory test unit of 10 kWe nominal power was installed during the project, which is now used in further research on dynamic behavior and control. It is still the only ORC demonstration unit in Flanders and has been very instructive in introducing representatives from industry, researchers and students to the technology.

A considerable part of the project execution consisted of case studies in response to industrial requests from several sectors. Detailed and concrete feasibility studies allowed us to define the current application area of waste heat recovery ORC in a better way. A knowledge center for waste heat recovery (www.wasteheat.eu) was initiated to consolidate the know-how and to advise potential users.

PROJECT RESULTS

The work was divided in the following main research lines.

Simulation and monitoring

Models of OR-cycles were developed within the project. As part of the hardware modeling, one laboratory plant and two large scale CHP plants were monitored over a period of two years. The acquired data delivered a valuable source for validation of component and cycle models. In order to compute annual time series for heat sources, several software tools were programmed. The behavior of heat sources containing the properties of various fluids (exhaust gases, hot air, hot water, steam, thermal oil), were implemented in the simulation environment Insel8. Furthermore, these heat source libraries have been adjusted for the use in the software package EES. REFPROP, DIPPR and FluidProp databases are used as reference for the thermophysical properties of working and heat transfer fluids. A further software tool for fast investigation of the influence of all parameters on cycle efficiency and generated power was developed. Automatic representation of the ORC cycle in Ts- and QT-diagrams is one of its features.

Business-economic context of energy investments

The first part of this work involved acquiring an understanding of decision-making policies within companies of our target group. The project was followed up closely by about 30 companies from several industrial sectors. In the other direction, our research ensured the correct interpretation of energy saving measures and investments, with a special attention to the situation of SMEs. This included general principles of investment evaluation, the contents, application and consequences of audit and benchmark convenants, but also less tangible aspects such as the importance of a green image and CO_2 neutrality.

The second part of this work consisted of integrating the economic conditions into the calculation tools. The total investment cost is considered based on the ORC module price and an estimation of maintenance costs, and via a sensitivity analysis of the internal rate of return (or payback time) an estimate of the room for additional investments and installation costs is given (see Fig. 1 for an example).

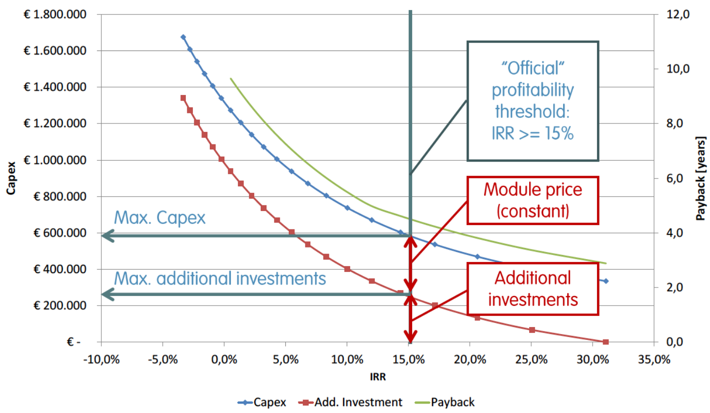

Figure 1: Economic evaluation tool for the analysis of ORC investment costs.

Heat exchangers for waste heat recuperation and cooling
Particular attention went to waste heat recovery from flue gases (acid dew point analysis), the detailed design of heat exchanger geometry (external dimensions, tube selection, fin spacing, heat transfer coefficients, and pressure drop calculations), and the choice between a cooling tower (wet cooler) or a direct air cooler (dry cooler).

Applicability of recent ORC research
Although the goals of the project did not include a contribution to the improvement of ORC designs, several external research lines were assessed for their implementation potential. These included cascade systems (with high and low temperature circuits), the Kalina cycle and the potential of mixtures of working fluids, adapted cycles (transcritical CO_2, expansion of saturated fluid in screw expanders, preheating and other elements from combined steam cycles), developments in generators and inverters. We are now involved in a follow-up project, ORCNext (www.orcnext.be), which focuses on advanced cycles, supercritical evaporators, expander design and selection, dynamic behavior and control, and the techno-economic analysis and design of the next generation ORC.

Follow-up of ORC supply and market developments
An up-to-date overview of available units is kept and the export of units to Europe/Flanders is advocated. Personal contacts and visits to installations were of key importance to supplement publicly available information. The database is linked to the ORC calculation tool, enabling the output of a quick technical and economic decision matrix, given the boundary conditions of the waste heat stream.

Benchmark steam turbine installation versus ORC
For several application areas (e.g. biomass burning, high temperature waste heat recovery) both the 'traditional' steam turbine technology and 'newer' ORC technology can be considered. Also in view of special interests from our user group of companies, a detailed study of the comparison of the two options was an important part of the project. A good understanding of the thermodynamic differences between the two cycles was obtained. This, however, was only a first step towards a full comparison. Real expander efficiencies, installation and operation cost differences, and regulatory aspects also determine the suitability range of each technology.

Benchmark alternative waste heat valorization technologies
Besides ORC, other methods exist to utilize waste heat:

- absorption and adsorption cooling;
- heat pumps that elevate the temperature level of the heat stream to a directly usable level;
- thermoelectric generators (TEG).

Besides a general study of technical and economic opportunities, the alternative technologies were in particular considered in the case studies. An energetic comparison was made between a heat driven absorption chiller and a compressor based chiller driven by ORC. We are now involved in a new project examining the feasibility of heat pumps for waste heat recovery in industry, with emphasis on high temperature applications (www.wasteheat.eu).

Combination CHP-ORC
This work was focused on the Flemish situation as support mechanisms for CHP are defined

regionally. The central theme was the calculation of relative primary energy savings, with a target value of a 5% increase by employing ORC. Some engine types (diesel, gas turbines) were considered, as well as the condition that condenser heat can be be recovered in the industrial process.

Test and demonstration setup

After considering systems based on small turbines or scroll expanders, a single screw expander setup was selected with 10 kWe nominal electric power (Fig. 2). The ORC was connected to

Figure 2: ORC test facility (middle), heating (left) and cooling (right) circuits.

a 250 kW thermal oil boiler and a water-glycol cooling loop (air cooled). Solkatherm was selected as working fluid. Lubricating oil circulates through the cycle to lubricate the rotor of the expander, while the bearings are lubricated using a by-pass pipe directly from the pump to the expander. The heat exchangers (evaporator, condenser, and recuperator – which can be bypassed) are brazed plate type. The ORC feed pump is multistage centrifugal. Flow meters, pressure and temperature sensors are installed on the ORC, heating and cooling loops. Adaptations of the setup (variable expander speed, fluid replacement unit, LabVIEW control and acquisition system) are currently underway within a new project (www.orcnext.be).

Case studies

Case studies formed the heart of the project. Waste heat streams were charted, less advanced heat recovery methods signaled, and ORC was benchmarked against alternatives. When ORC was the preferred technology, available systems adapted to the situation were suggested. A cost-benefit analysis was presented and in some cases actual installation followed or was further analyzed by an engineering firm. Installed ORCs were followed up. Application areas included an incinerator plant; a CO_2 afterburner in foam glass production; furnace exhaust and cooling water in a steel wire plant; exhaust of a gas turbine in a paper mill; low pressure steam in a chemical plant; heat recovery in a automobile paint shop; cooling water and exhaust of walking beam furnace in steel production; a clay grain production furnace; and low temperature waste stream in a water treatment facility. Because of the confidentiality of some process information, specific results for the cases cannot be given. We can however report several interesting general conclusions.

CONCLUSION

The final project report is currently in preparation. The ORC 2013 conference is well timed to present our main conclusions. A shortened version of the report can also be considered for publication.